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FOR

POWER MANAGEMENT METHOD FOR MANAGING DELIVER OPPORTUNITIES IN A WIRELESS COMMUNICATION SYSTEM

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POWER MANAGEMENT METHOD FOR MANAGING DELIVER OPPORTUNITIES IN A WIRELESS COMMUNICATION SYSTEM

CROSS REFERENCE TO RELATED APPLICATIONS

This application is one of a set of U.S. patent applications consisting of Serial No. 10/xxx,xxx filed as attorney docket No. Kampen 1-13 and Serial No. 10/yyy,yyy filed as attorney docket No. Kampen 2-15, both of which were filed on the same date and the teachings of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to communication equipment and, more specifically, to equipment for wireless local area networks (WLANs).

Description of the Related Art

IEEE Standard 802.11, the teachings of which are incorporated herein by reference, has emerged as a prevailing technology for broadband access in WLAN systems and is regarded by many as a wireless version of Ethernet. The 802.11 medium access control (MAC) specifications provide that a wireless station (STA) may be in one of two power states: awake state and doze state. In the awake state, the STA is fully powered and is able to transmit and receive frames. In contrast, in the doze state, the STA consumes very low power and is not able to transmit or receive. The manner in which an STA transitions between these two states is determined by the STA power management mode. The 802.11 MAC specifications define two power management modes: active mode and power save (PS) mode. In active mode, the STA is always awake and therefore consumes substantial power. In PS mode, the STA is in the awake state only for relatively short periods of time while spending the remaining time in the doze state, which significantly reduces the amount of consumed power.

According to the 802.11 standard, a WLAN system having one or more STAs functioning in PS mode may operate as follows. The access point (AP) of the WLAN does not arbitrarily transmit frames to said STAs, but buffers the frames and transmits them at designated times. The AP identifies the STAs, for which the AP currently has frames, in a traffic indication map (TIM) provided with a beacon. With knowledge of

beacon schedule, each STA functioning in PS mode awakes for beacons and determines by interpreting the TIM whether the AP has a buffered frame for that STA. Upon determining that the AP currently has a buffered frame, the STA transmits a PS-Poll frame indicating that it is awake and is ready to receive. In response, the AP may either transmit the buffered frame immediately or acknowledge receipt of the PS-Poll frame and transmit the buffered frame at a later time. The STA remains in the awake state to await the frame transmission.

One problem with the above-described operating method is that it typically creates a transmission overhead of one PS-Poll frame per each buffered frame. As a result, an application employing relatively small data frames exchanged with relatively high periodicity, e.g., interactive voice over WLAN, will create a disadvantageously large transmission overhead. Another problem is that the delivery of buffered frames tends to be concentrated around beacons, which creates congestion, thereby increasing the number of collisions and reducing effective channel capacity.

SUMMARY OF THE INVENTION

Problems in the prior art are addressed, in accordance with the principles of the present invention, by a power management method, in which duration of deliver opportunities for a wireless station (STA) of a WLAN system is managed using a designated sub-field of the frame control field in a MAC header. Either the STA or the access point (AP) can terminate the deliver opportunity, e.g., based on the amount traffic. In one embodiment, the STA is adapted (i) to use the power management sub-field to communicate its power state to the AP and (ii) to run a maximum-wait timer, which starts when the AP is informed that the STA is in the awake state. The STA transitions to the doze state either when it has received a data frame from the AP or when the maximum-wait timer runs out. In another embodiment, the AP and STA manage deliver opportunities by entering a new mode of operation referred to as interactive traffic power management (ITPM) mode. During this mode the power management sub-field is ignored and the more data sub-field is used to communicate the availability of data and to manage transitions of the STA between the awake and doze states. Embodiments of the invention improve WLAN system performance when the traffic load is such that data frames become available for transmission both at the STA and AP at relatively regular intervals, which is typically the case for interactive voice-over-WLAN applications.

Advantageously, the traffic load is spread away from beacons, which alleviates congestion. In addition, both upstream and downstream frames can be transmitted using the same deliver opportunity, which reduces the transmission overhead.

According to one embodiment, the present invention is, at a station of a contention-based WLAN system in which the station is adapted to operate in awake and doze states, a method comprising: (A) with the station in the awake state and an access point (AP) of the system informed that the station is in the awake state, transmitting to the AP a closing frame, wherein a designated bit in the closing frame informs the AP that the station will transition to the doze state; and (B) transitioning the station from the awake state to the doze state.

According to another embodiment, the present invention is, at an access point (AP) of a contention-based WLAN system in which a station is adapted to operate in awake and doze states, a method comprising: (A) with the station in the awake state and the AP informed that the station is in the awake state, receiving from the station a closing frame, wherein a designated bit in the closing frame informs the AP that the station will transition to the doze state; and (B) refraining from transmitting frames to the station until a notification is received that the station is in the awake state.

BRIEF DESCRIPTION OF THE DRAWINGS

Other aspects, features, and benefits of the present invention will become more fully apparent from the following detailed description, the appended claims, and the accompanying drawings in which:

Fig. 1 shows schematically the structure of the frame control field in a MAC header;

Figs. 2A-C graphically show how the power management (PM) bit of a MAC header is used to manage transmissions between an AP and an STA according to one embodiment of the present invention;

Figs. 3A-C graphically show how the more data (MD) bit of a MAC header is used to manage transmissions between an AP and an STA according to another embodiment of the present invention; and

Fig. 4 shows a block diagram of a WLAN system in which the methods illustrated in Figs. 2-3 may be practiced.

DETAILED DESCRIPTION

Reference herein to "one embodiment" or "an embodiment" means that a particular feature, structure, or characteristic described in connection with the embodiment can be included in at least one embodiment of the invention. The appearances of the phrase "in one embodiment" in various places in the specification are not necessarily all referring to the same embodiment, nor are separate or alternative embodiments mutually exclusive of other embodiments.

Each MAC frame in an 802.11-compliant WLAN comprises a set of fields that occur in a fixed order in each frame. Generally, the following three basic frame components are distinguished: a MAC header, a frame body, and a frame check sequence (FCS). A MAC header contains frame control, duration, address, and sequence control information; a variable-length frame body contains information specific to the frame type; and an FCS contains an IEEE 32-bit cyclic redundancy code.

Fig. 1 shows schematically the structure of the frame control field in a MAC header. More specifically, the frame control field has the following sub-fields: Protocol Version (bits B0 – B1); Type (bits B2 – B3); Subtype (bits B4 – B7); To Distribution System (bit B8); From Distribution System (bit B9); More Fragments (bit B10); Retry (bit B11); Power Management (bit B12); More Data (bit B13); Wired Equivalent Privacy (bit B14); and Order (bit B16). Of interest to this specification are the Power Management (PM) and More Data (MD) sub-fields (bits), the usage of which is explained in more detail below.

According to the 802.11 standard, the PM bit is used to indicate the mode that an STA will be in after the successful completion of the frame exchange sequence. PM bit values of 1 and 0 indicate that the STA will be in PS mode and active mode, respectively. The PM bit value is always set to 0 in frames transmitted by the AP. The MD bit is used to indicate to an STA in PS mode that one or more frames are buffered at the AP for transmission to that STA. More specifically, an MD bit value of 1 indicates that at least one frame is available for transmission to the STA; and an MD bit value of 0 indicates that there are no buffered frames. The use of the MD bit in frames transmitted from STA to AP is not currently defined in the 802.11 standard.

Figs. 2A-C graphically show how the PM bit is used to manage transmissions between an AP and an STA according to one embodiment of the present invention. More specifically, instead of or in addition to using PS-Poll frames to create deliver

opportunities for the AP, the STA creates deliver opportunities using the PM bit of regular data and/or control frames exchanged with the AP, where the term "deliver opportunity" refers to a condition existing when (i) the STA is awake and (ii) the AP has been notified that the STA is awake, which creates an opportunity for the AP to deliver to the STA any buffered frames it might have for that STA. Since such creation of deliver opportunities is correlated with the amount of traffic exchanged between the STA and AP, more than one deliver opportunity may be presented to the AP during a single inter-beacon period. This spreads the traffic load away from beacons and therefore alleviates congestion. In addition, the above-mentioned PS-Poll overhead is reduced.

In one embodiment, the STA is configured to run one or more timers regulating transitions of said STA between the doze and awake states. For example, a first timer, hereafter referred to as the maximum-wait (MW) timer, starts when the AP has been notified that the STA transitioned to the awake state. When the MW timer reaches a selected threshold value (i.e. runs out), the STA notifies the AP and transitions back to the doze state. Similarly, a second timer, hereafter referred to as the periodicity timer, starts when the STA transitions to the doze state. When the periodicity timer runs out, the STA transitions to the awake state and notifies the AP that it is now awake. In one configuration, the first and second timer threshold values are selected and/or adjusted based on the characteristics of traffic between the STA and AP. For example, such characteristics may include data flow rate (i.e., amount of data presented for transmission per unit time), data fragmentation, fluctuations of the flow rate, etc.

Fig. 2A shows a representative frame exchange when both the AP and the STA have data frames available for transmission. Suppose that prior to time t0 the AP has been notified that the STA is in the doze state. When at time t1 > t0 frame Data 1 becomes available for transmission from the AP to the STA, the AP queues that frame in a buffer without attempting to transmit it to the STA. When at time t2 > t1 frame Data 2 becomes available for transmission from the STA to the AP, the STA transitions to the awake state and proceeds to transmit frame Data 2 with the PM bit in its header set to 0. The AP acknowledges receipt of frame Data 2 with an ACK frame **202** and is now notified that the STA is awake. Upon receipt of ACK frame **202**, the STA starts the MW timer at time t3.

The upper time axis in Fig. 2A illustrates a first scenario, in which, before the MW timer runs out, the AP transmits frame Data 1. Accordingly, the STA acknowledges

receipt of frame Data 1 with an ACK frame **204** having its PM bit set to 1, transitions to the doze state, and starts the periodicity timer. The lower time axis in Fig. 2A illustrates a second scenario, in which the MW timer has run out before frame Data 1 is transmitted. This may occur, for example, due to the transmission medium being busy or traffic to other STAs having higher priority than the traffic to this particular STA. When the MW timer runs out at time t4, the STA sends a Null frame **206** having its PM bit set to 1. After the AP acknowledges receipt of frame **206** with an ACK frame **208**, the STA transitions to the doze state and starts the periodicity timer.

Fig. 2B shows a representative frame exchange when only the STA has data frames available for transmission. Similar to the situation illustrated in Fig. 2A, prior to time t0 the AP has been notified that the STA is in the doze state. When at time t5 > t0 frame Data 3 becomes available for transmission from the STA to the AP, the STA transitions to the awake state and proceeds to transmit frame Data 3 with the PM bit in its header set to 0. The AP acknowledges receipt of frame Data 3 with an ACK frame **210** and is now notified that the STA is awake. Upon receipt of ACK frame **210**, the STA starts the MW timer at time t6. However, since the AP has no data to transmit to the STA, the MW timer runs out at time t7, which triggers the transmission of a Null frame **212** having its PM bit set to 1. After the AP acknowledges receipt of frame **212** with an ACK frame **214**, the STA transitions to the doze state and starts the periodicity timer.

Fig. 2C shows a representative frame exchange when only the AP has data frames available for transmission. Similar to the situations illustrated in Figs. 2A-B, prior to time t0 the AP has been notified that the STA is in the doze state. When at time t8 > t0 frame Data 4 becomes available for transmission from the AP to the STA, the AP queues that frame in a buffer without attempting to transmit it to the STA. Since the STA has no frames to transmit, it will remain in the doze state until the periodicity timer runs out at time t9 > t8. At that point, the STA awakes and transmits a Null frame **216** having its PM bit set to 0, which notifies the AP that the STA is now in the awake state. After the AP acknowledges receipt of frame **216** with an ACK frame **218**, the STA starts the MW timer at time t10.

Subsequent events shown in Fig. 2C are similar to those shown in Fig. 2A after time t3. More specifically, the upper time axis in Fig. 2C illustrates the scenario in which the AP transmits frame Data 4 before the MW timer runs out. Accordingly, the STA acknowledges receipt of frame Data 4 with an ACK frame **220** having its PM bit set to 1,

transitions to the doze state, and starts the periodicity timer. Similarly, the lower time axis in Fig. 2C illustrates the scenario in which the MW timer has run out at time t11 before frame Data 4 could be transmitted. Accordingly, the STA transmits a Null frame **222** having its PM bit set to 1. After the AP acknowledges receipt of frame **222** with an ACK frame **224**, the STA transitions to the doze state and starts the periodicity timer.

Embodiments of the power management method illustrated in Figs. 2A-C are particularly advantageous when the traffic load is such that, for every deliver opportunity, there is at least one frame available for upstream and downstream transmissions (e.g., the situation shown in Fig. 2A). In this case, one exchange can combine both transmissions without incurring the overhead of PS-Poll frames. Some overhead of Null frames may be incurred when either the AP or STA does not have an available frame (e.g., Figs. 2B-C). Embodiments of the method illustrated by Figs. 2A-C are also advantageous when frames become available for transmission with periodicity smaller than the beacon periodicity. In that case, buffer delays are reduced due to the presence of additional deliver opportunities between beacons. Furthermore, since the STA controls creation of deliver opportunities, frame processing at the AP can be implemented without departing from that specified in the 802.11 standard. This makes it possible for a WLAN system to have, without compatibility issues, prior art STAs alongside with STAs configured in accordance with embodiments of the method of Figs. 2A-C.

Figs. 3A-C graphically show how the MD bit is used to manage transmissions between an AP and an STA according to another embodiment of the present invention. More specifically, instead of or in addition to using PS-Poll frames to create deliver opportunities for the AP, the AP and STA create deliver opportunities by entering a new mode of operation, hereafter referred to as interactive traffic power management (ITPM) mode. In ITPM mode, the PS and MD bits are interpreted differently than within the current 802.11 standard specifications. For example, in ITPM mode, the PM bit is ignored and the MD bit is used to manage transitions of the STA between the awake and doze states. As such, the ITPM mode requires an extension of the 802.11 standard. Similar to the method illustrated in Figs. 2A-C, embodiments of the method illustrated in Figs. 3A-C spread the traffic load away from beacons and reduce the transmission overhead.

To enter ITPM mode, the STA and AP exchange action frames requesting and confirming said mode. For example, in one configuration, the STA initiates entry into

ITPM mode by transmitting a first action frame to the AP. An action frame is a management frame defined in IEEE Draft Standard 802.11e (version D4.0 of November, 2002), the teachings of which are incorporated herein by reference. The body of an action frame has a set of sub-fields, several of which are reserved for future expansions of the standard. According to one embodiment of the present invention, one of the reserved sub-fields is used to initiate or terminate the ITPM mode. More specifically, values of 1 and 0 in the ITPM sub-field correspond to the initiation and termination, respectively, of the ITPM mode. After receiving the first action frame having its ITPM sub-field value set to 1, the AP transmits a second action frame having its ITPM sub-field value also set to 1, which confirms acceptance of the ITPM mode. After this confirmation, the STA transitions into the doze state and the AP begins buffering data frames designated for delivery to the STA. In an alternative configuration, the AP may similarly initiate entry into ITPM mode.

While in ITPM mode, the STA and AP interpret the MD bit as follows. For frames transmitted from the STA to the AP, MD bit values of 1 and 0 indicate to the AP that the STA will be in the doze and awake state, respectively, until further notice. For frames transmitted from the AP to the STA, an MD bit value of 1 indicates that the AP has at least one data frame available for transmission to that STA and that the STA will stay awake until transition to the doze state is confirmed. An MD bit value of 0 indicates that the AP has no data frames for the STA and that the STA may transition to the doze state.

In ITPM mode, either an AP or an STA can create deliver opportunities by appropriately setting the MD bit value in a transmitted frame. In one configuration, the STA runs a periodicity timer starting when the STA transitions to the doze state. When the periodicity timer runs out, the STA transitions to the awake state and notifies the AP that it is now awake by transmitting a Null frame having its MD bit set to 0. Selection of a threshold value for the periodicity timer may be similar to that described above for the method of Figs. 2A-C.

Fig. 3A shows a representative frame exchange in ITPM mode when both the AP and the STA have data frames available for transmission. Suppose that at time t0 the AP and STA have commenced the ITPM mode and the STA transitioned into the doze state. When at time t1 > t0 frame Data 1 becomes available for transmission from the AP to the STA, the AP queues that frame in a buffer without attempting to transmit it to the STA.

When at time t2 > t1 frame Data 2 becomes available for transmission from the STA to the AP, the STA transitions to the awake state and proceeds to transmit frame Data 2 with the MD bit in its header set to 0. The transmission may occur immediately after frame Data 2 has become available or at a later time, e.g., selected in accordance with a previously negotiated transmission schedule. The AP acknowledges receipt of frame Data 2 with an ACK frame **302** having its MD bit set to 1, which informs the STA that the AP has data and instructs the STA to stay awake. The AP then transmits frame Data 1 with its MD bit set 0, which indicates that the AP has no additional frames to transmit. The STA acknowledges receipt of frame Data 1 with an ACK frame **304** having its MD bit set to 1, transitions to the doze state, and starts the periodicity timer.

Fig. 3B shows a representative frame exchange in ITPM mode when only the STA has data frames available for transmission. Similar to the situation illustrated in Fig. 3A, at time t0 the ITPM mode has started and the STA transitioned into the doze state. When at time t3 > t0 frame Data 3 becomes available for transmission from the STA to the AP, the STA transitions to the awake state and proceeds to transmit frame Data 3 with the MD bit in its header set to 0. The AP acknowledges receipt of frame Data 3 with an ACK frame **306** having its MD bit set 0, which indicates that the AP has no frames to transmit. Upon receipt of ACK frame **306**, the STA transitions to the doze state and starts the periodicity timer.

Fig. 3C shows a representative frame exchange in ITPM mode when only the AP has data frames available for transmission. Similar to the situations illustrated in Figs. 3A-B, at time t0 the ITPM mode has started and the STA transitioned into the doze state. When at time t4 > t0 frames Data 4 and Data 5 become available for transmission from the AP to the STA, the AP queues those frame in a buffer without attempting to transmit them to the STA. Since the STA has no frames to transmit, it will remain in the doze state until the periodicity timer runs out at time t5 > t4. At that point the STA awakes and transmits a Null frame **308** having its MD bit set to 0, which notifies the AP that the STA is now in the awake state. The AP acknowledges receipt of frame **308** with an ACK frame **310** having its MD bit set to 1, which instructs the STA to stay awake. The AP then transmits frame Data 4 having its MD bit set to 1.

The upper time axis in Fig. 3C illustrates a first scenario, in which the STA decides to accept further transmissions from the AP. Accordingly, the STA acknowledges receipt of frame Data 4 with an ACK frame **312** having its MD bit set to 0.

The AP then transmits frame Data 5 having its MD bit set to 0, indicating that further frames are not yet available. The STA acknowledges receipt of frame Data 5 with an ACK frame **314** having its MD bit set to 1, transitions to the doze state, and starts the periodicity timer. The lower time axis in Fig. 3C illustrates a second scenario, in which the STA decides to interrupt further transmissions from the AP. A possible reason for the interruption can be, for example, a limitation in the particular STA embodiment that imposes a restriction on the length of time for the continuous (uninterrupted) use of full awake power. Accordingly, the STA transmits an ACK frame **316** having its MD bit set to 1. After the transmission of frame **316**, the STA is allowed to transition to the doze state and start the periodicity timer.

Similar to embodiments of the power management method illustrated in Figs. 2A-C, ITPM mode is particularly advantageous when the traffic load is such that data frames become available for transmission both at the STA and AP at relatively regular intervals, which is typically the case for interactive voice-over-WLAN applications. Using the MD bit, the STA can offer a deliver opportunity and the AP can accept or deny that opportunity. As a result, frame delivery is decoupled from the beacon schedule. In addition, both upstream and downstream frames can be delivered using the same deliver opportunity, which reduces the transmission overhead.

Fig. 4 shows a block diagram of a WLAN system **400** in which embodiments of the method illustrated in Figs. 2-3 may be practiced. System **400** has an AP **402** and four battery-powered STAs **404a-d**. Each STA **404** is adapted to operate in the awake and doze states. Each STA **404** comprises a processor, a transceiver, and an antenna. For example, STA **404a** has a processor **414**, a transceiver **424**, and an antenna **434**. Similarly, AP **402** comprises a processor **412**, a transceiver **422**, and an antenna **432**. Each STA **404** transitions between the awake and doze states in accordance with a selected embodiment of the present invention or as specified in the 802.11 standard and exchanges frames with AP **402** using the corresponding procedure. The operation of each STA **404** and AP **402** is controlled by the corresponding processor executing software or firmware instructions corresponding to the selected power management scheme.

While this invention has been described with reference to illustrative embodiments, this description is not intended to be construed in a limiting sense. Although the invention was described in reference to PM and MD bits, the invention may

also be adapted to utilize other bits of the MAC header. Various modifications of the described embodiments, as well as other embodiments of the invention, which are apparent to persons skilled in the art to which the invention pertains are deemed to lie within the principle and scope of the invention as expressed in the following claims.

Although the steps in the following method claims, if any, are recited in a particular sequence with corresponding labeling, unless the claim recitations otherwise imply a particular sequence for implementing some or all of those steps, those steps are not necessarily intended to be limited to being implemented in that particular sequence.

The present invention may be implemented as circuit-based processes, including possible implementation on a single integrated circuit. As would be apparent to one skilled in the art, various functions of circuit elements may also be implemented as processing steps in a software program. Such software may be employed in, for example, a digital signal processor, micro-controller, or general-purpose computer.

The present invention can be embodied in the form of methods and apparatuses for practicing those methods. The present invention can also be embodied in the form of program code embodied in tangible media, such as floppy diskettes, CD-ROMs, hard drives, or any other machine-readable storage medium, wherein, when the program code is loaded into and executed by a machine, such as a computer, the machine becomes an apparatus for practicing the invention. The present invention can also be embodied in the form of program code, for example, whether stored in a storage medium, loaded into and/or executed by a machine, or transmitted over some transmission medium or carrier, such as over electrical wiring or cabling, through fiber optics, or via electromagnetic radiation, wherein, when the program code is loaded into and executed by a machine, such as a computer, the machine becomes an apparatus for practicing the invention. When implemented on a general-purpose processor, the program code segments combine with the processor to provide a unique device that operates analogously to specific logic circuits.